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An examination of the rectangular coördinates resulting from the solutions (Table II) shows that nine out of the entire twelve values of Y and all of the values from the small μ_α, are smaller for the northern than for the southern stars, indicating smaller average parallactic displacement for the northern than for the southern stars.

Taking the stars of type B as the best marked example, if we use the value of Y derived from the *southern* stars to determine D for the *northern* stars, we obtain essentially the same D for both northern and southern stars, a value which agrees well with that obtained from the radial velocities of the same stars and with that from the radial velocities of all of the spectral classes. This will be true in principle also for the other cases, but appears to be complicated in the later types by other factors.

Summary.—1. The position of the apex of solar motion depends upon the proper motions in right ascension of the stars used. The differences appear to be greatest in declination, the stars of large proper motion yielding apices south of those from stars with small proper motion. This effect is shown in the results both from proper motions and radial velocities.

2. The differences in D of the apices of solar motion as derived by other investigators from radial velocities and from proper motions are consistent and they appear in general to be greater for the stars of late than for those of early type. This discordance appears to arise chiefly from the proper motions of the northern stars and to be satisfactorily explained by the assumption that the parallactic displacement of the stars is systematically less in the northern sky.

The details of this investigation have been sent to the *Astrophysical Journal.*

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[1] These PROCEEDINGS, **2**, 1916, (376–378); *Astroph. J., Chicago, Ill.*, **44**, 1916, (103–116).

[2] *Contrib. Mount Wilson Solar Obs.*, No. 105.

[3] *Berkeley, Lick Obs., Univ. Cal., Bull.*, No. 196, p. 128.

HYDROLOGY OF THE ISTHMUS OF PANAMA

By Brig. Gen. Henry L. Abbot
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Read before the Academy, November 13, 1916

The Panama Canal being now opened to traffic, there remains for study only one important hydraulic problem—the sufficiency of the available water supply to meet the needs for lockage, for mechanical power to operate the canal and railroad, and for the electric lighting of the Canal Zone. It should not be forgotten, however, that if a larger volume of water be desirable for these and other uses, the plan proposed by the New French Company to supplement the volume of its smaller projected lake is still available; namely, the construction of a masonry dam near Alhajuela, where a good site exists for creating an upper lake to hold back the surplus water which during the rainy months now runs to waste through the spillway.

The Canal Zone lies between the ninth and tenth degrees of north latitude in a region of exceptional rainfall; where the sun, closely followed by rain clouds raised from the oceans in his annual journey between the tropics, exerts a controlling influence upon the volume of local rainfall. When near his southern limit, in January, February, March and April, precipitation upon the Isthmus is at its minimum; December and May are usually intermediate in volume; in the remaining six months, when near his northern limit, heavy downpours are the rule. Furthermore, the local annual rainfall is not uniform across the Isthmus. As one passes from the Atlantic to the Pacific coast, the volume falls off gradually from about 130 inches at Colon to about 70 inches at Panama. It will be noticed that even the latter is more than double the usual downfall in the United States, a fortunate circumstance for our great artery of commerce. Another local advantage is the fact that the atmosphere of the Isthmus is nearly saturated with aqueous vapor, which largely reduces the losses by lake evaporation. Our hydraulic problem seems therefore to be specially concerned with Isthmian rainfall and outflow, and the relation between them.

To determine accurately the average annual rainfall at any locality, the records should cover at least half a century. Although the Isthmus has been known to civilization for more than four hundred years, the first annual rainfall records date from 1863, when they were begun by the agents of the Panama Railroad Company. As to the outflow from the watershed, the records are even less complete. The volume received from the clouds, after reduction by evaporation, by plant growth, and by possible infiltration, represents the available flow at the dam site. To determine to what extent existing data throw light upon this quantity, has seemed to me to be of primary interest.

The earlier records are given in a paper published in the *Monthly Weather Review* in May, 1899; they include those of the Railroad company, and those at that date collected by the two French Companies and the Liquidation. A gap of a few years in the former is supplied by a paper by Mr. A. P. Davis, published in the Twenty-second Annual

Report of the United States Geological Survey for 1900–1901. These data are supplemented and discussed by the writer in papers published in the *Monthly Weather Review* of February, 1904, and of June, 1908, together with some later data collected by the American engineers. In March, 1913, Mr. Caleb M. Saville contributed a valuable paper upon the Hydrology of the Canal to the Transactions of the American Society of Civil Engineers, bringing the records up to 1910. The Annual Reports of the Isthmian Canal Commission, of course, cover the American operations. The first point for consideration is, how these data can best be grouped for study?

The narrow limits to which the earlier observations were restricted suggest that the basin of the Chagres River above Bohio should be adopted until Gatun Lake began to fill early in 1910. Its area has been accurately determined by recent surveys to be 779 square miles. The early rain records were mostly restricted to Colon and Gamboa. Fortunately, Colon is situated near the Atlantic Coast line where the rainfall is largest, and Gamboa well represents the Pacific limit of the watershed. A careful analysis of the more ample records of recent years (1898–1907) has shown that the average rainfall in the basin above Bohio is about 89% of that at Colon, 124% of that at Gamboa, and 52% of the aggregate of the two stations. To avoid a change in the standard, these ratios have been used throughout the following table to estimate the annual rainfall in the basin; and where a few dry months are missing in the early railroad records the vacancies have been supplied by the mean values of the missing months.

The Chagres River is a torrential stream, and the first French Company early established a fluviograph at Gamboa to register continuously the heights of the water. This record has been carefully kept since 1883; until the rise of the lake in 1910 began to affect the local water level. At the times of freshets the oscillations are so sudden that their number and duration are readily noted, and they furnish valuable checks upon the discharge estimates. For this study they are assumed to begin and end at a stage 10 feet above low water, which is rarely exceeded.

Accurate measurements of discharge were inaugurated by the Liquidation and the New French Company, the continuous record dating from 1890. The annual outflow is given in the tables under the forms of cubic feet per second and depth in inches upon the watershed; the latter to permit a direct comparison with the rainfall. Years of great floods are also indicated, with the same object in view.

The first table is intended to present, for the basin above Bohio, all available hydraulic data prior to the date when Gatun Lake began to fill, with some later figures added for comparison with those of the second table, which includes the entire watershed above Lake Gatun during the filling of the lake. In future studies this latter basin will doubtless be adopted, as the net outflow is easily determined and rainfall measurements are now made at many stations. For the second table I first[1] adopted the mean of the rainfall records at nine stations—Colon, Gatun, Trinidad, Camacho, Empire, Culebra, Gamboa, Alhajuela and El Vigia—as well representing the average volume falling upon the lake watershed near the Canal Zone. Seven new stations then unknown to me had been added, and the figures now given are taken from the noteworthy paper by Mr. Willson in the *Transactions of the International Engineering Congress at San Francisco.*

HYDROLOGY OF THE WATERSHED ABOVE BOHIO; 779 SQUARE MILES

YEAR	PRECIPITATION		IN THE BASIN ABOVE BOHIO			GAMBOA FRESHETS		AUTHORITY
	Colon Inches	Gamboa Inches	Rainfall Inches	Outflow		Annual No.	Duration Hours	
				Ft.-sec.	Inches			
1863	134.3		120					Panama Railroad Records
1864	123.4		110					
1865	107.4		96					
1866	129.7		115					
1867	120.8		108					
1868	120.0		107					
1869	114.8		102					
1870	149.6		133					
1871	99.6		81					
1872	168.5		150					
1873	87.1		78					
1874	137.7		123					
1875	94.7		84					
1876	124.5		111					
1877	115.5		103					
1878	86.7		77					
*1879	164.2		130					
1880	136.4		121					
1881	102.3	89.5	100					de Lesseps French Cie
1882	124.1	79.6	106					
1883	115.3	76.6	100			21	201	
1884	86.5	95.9	95			25	334	
*1885	146.3	97.5	127			37	437	
1886	137.2	102.9	125			43	437	
1887	154.9	136.2	151			46	709	
*1888		102.6	127			29	596	

* Great flood of the Chagres River.

HYDROLOGY OF THE WATERSHED ABOVE BOHIO; 779 SQUARE MILES—*continued*

YEAR	PRECIPITATION		IN THE BASIN ABOVE BOHIO			GAMBOA FRESHETS		AUTHORITY
	Colon Inches	Gamboa Inches	Rainfall Inches	Outflow		Annual No.	Duration Hours	
				Ft.-sec.	Inches			
1889		75.7						Collapse. Liquidation.
*1890	154.3	105.0	135	6,304	110.0	34	308	
1891	124.7	77.7	105	4,476	78.1	10	115	
1892	145.3	104.4	130	6,513	113.6	24	269	
*1893	131.9	117.8	130	7,081	123.3	12	220	
1894	153.7	90.6	127	6,098	106.4	25	263	
1895	151.5		135	4,482	78.2	7	54	The New French Cie
1896	131.5		117	4,216	73.5			
1897	138.0	107.8	128	4,830	84.2	16	157	
1898	115.5	82.6	103	3,944	68.8	8	51	
1899	133.0	80.0	111	3,384	59.0	8	57	
1900	116.1	78.7	101	3,509	61.2	12	84	
1901	107.7	91.6	104	3,855	67.2	13	107	
1902	112.6	97.7	109	4,179	72.9	5	37	
1903	126.3	99.3	117	3,958	69.0	12	94	
1904	126.9	84.5	110	4,110	71.7	13	94	U. S. in charge.
1905	115.4	82.2	103	2,800	48.8	6	48	
*1906	138.1	97.8	123	4,169	72.7	12	178	
1907	125.6	78.1	106	3,597	62.7	11	69	
1908	137.7	77.5	112	3,732	65.1	14	131	
*1909	183.4	122.1	159	7,335	128.0	27	466	
1910	150.0	116.0	138	6,340	110.6	15	77	Lake began to fill
1911	112.8	70.6	95					
1912	117.6	89.1	107					
1913	131.2	86.3	113					
1914	132.7	77.4	109					

* Great flood of the Chagres River.

HYDROLOGY OF THE WATERSHED ABOVE LAKE GUTUN; 1,320 SQUARE MILES

YEAR	LAKE ABOVE MEAN SEA LEVEL FEET	IN THE LAKE WATERSHED			LAKE EVAPORATION. FOOT-SECONDS
		Rainfall inches	Net outflow		
			Foot-seconds	Inches	
*1909	3.63	162.42	10,704	110.1	
1910	13.07	149.66	11,938	122.9	
1911	15.15	98.41	5,710	58.8	
1912	31.24	102.83	4,985	51.3	
1913	57.87	102.40	5,272	54.3	484
1914	85.26	100.54	5,118	52.7	704
1915	86.17	118.17	7,106	80.2	733

* Great flood of the Chagres River.

An inspection of these tables shows a satisfactory correspondence between the observed annual rainfall and the outflow and river oscillations as indicated by the number and duration of the freshets. There is, furthermore, a suggestion of a tendency to a progressive annual change between years of maxima and minima in these quantities, which is worthy of notice. If future records confirm this suggestion, it will be needful to study the reason for it, as is now the case with solar spots, aurora borealis, and other natural phenomena. As to the second table, it must not be forgotten that it covers a period when the area of the lake was gradually increasing, causing a variable loss due to evaporation. The values given for it for the last three years are taken from the official reports, and are based probably on direct measurements.

The tropical conditions of the Canal Zone are so different from those in the Continental United States that it is interesting to compare them. This may be done from Rafter's tables, in his valuable paper published as the Water-Supply and Irrigation Paper, No. 80, of the Geological Survey. It is done in the following table.

AVERAGE RAINFALL, RUN-OFF, AND DIFFERENCE

WATERSHED	AREA SQUARE MILES	PERIOD YEARS	RAIN-FALL INCHES	LOSSES			
				By Outflow		By Evap. Etc.	
				Inches	Per cent	Inches	Per cent
Muskingum River	5,828	8	39.7	13.1	33	26.6	67
Genessee River	1,070	9	40.3	14.2	35	26.1	65
Croton River	339	23	49.4	22.8	46	26.6	54
Lake Cochituate	19	38	47.1	20.3	43	26.8	57
Sudbury River	78	26	46.1	22.6	49	23.5	51
Mystic Lake	27	18	44.1	20.0	45	24.1	55
Neshaminy Creek	139	16	47.6	23.1	49	24.5	51
Perkiomen Creek	152	16	48.0	23.6	50	24.4	50
Tohickon Creek	102	15	50.1	28.4	57	21.7	43
Hudson River	4,500	14	44.2	23.3	53	20.9	47
Pequannock River	64	9	46.8	26.8	57	20.0	43
Connecticut River	10,234	8	43.0	22.0	51	21.0	49
Chagres River	779	21	118.1	82.1	69	36.0	31
Gatun Lake Basin	1,320	6	119.4	75.0	63	28.3	24

An inspection of the last four columns will show how much more favorable to the operation of a canal are the hydraulic conditions prevailing upon the Isthmus than those existing near the Atlantic Coast of the United States. Considerably more than double the volume of rainfall is available, and the losses from evaporation, plant growth, and percolation are represented by only about 30% as against 50% of that volume. As stated above, it remains to be determined by the observations of many future years whether there is a tendency to a normal variation in annual rainfall upon the Isthmus, as seems to be suggested by the figures already of record.

[1] In a paper which appeared in *Professional Memoirs, Corps of Engineers, U.S.A.*, for November-December, 1915.

THE METEOR SYSTEM OF PONS-WINNECKE'S COMET

By Charles P. Olivier

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Communicated by E. W. Morley and read before the Academy, November 14, 1916

The National Academy of Sciences, by two grants from the J. Lawrence Smith Fund, having been the means of greatly extending the membership and work of the American Meteor Society, it seems well to report to the Academy the most interesting single result of the work so far obtained.

Late in May and early in June of this year two of our observers, Mr. John Koep and Mr. Philip Trudelle, both of Chippewa Falls, Wis., sent in a series of observations which showed that meteors were at least three times as numerous as is usual for the time of the year mentioned. This attracted immediate attention and the observations were worked up without delay. The orbits, which corresponded to the positions found for the radiants, were then computed. As several of the orbits turned out to have the same elements, a search was next made to see if any of the known comets had a similar orbit.

At once it was seen that Pons-Winnecke's Comet fulfilled the conditions excellently and there was no doubt that the meteors and the comet had a common origin, and that another case of the connection between a meteor stream and a comet had been found.

The first orbits for the meteors had been computed on the usual assumption that they moved with a parabolic velocity, but there were obvious reasons to show that this was only a first approximation. The orbits were then all computed as elliptical, assuming their major axes equal to that of the comet. This set made a far better agreement with the elements of the comet's orbit and put the connection beyond question.

Before speaking further about the meteors themselves, it will be of interest to review briefly the history of this rather remarkable comet. Discovered by Pons in 1819, no further observations were obtained until